Recent progress and the future directions of the Canadian weather and environmental prediction systems : optimizing research to operations mechanisms

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Director General
Weather and Environmental Operations
Meteorological Service of Canada

First Virtual US-Canada Border Conference 25-26 September 2013

Outline

- A bit of context….

- Where we are.

- Where we are heading

- Optimizing research to operations

- Human and technological dimensions

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Acknowledgements
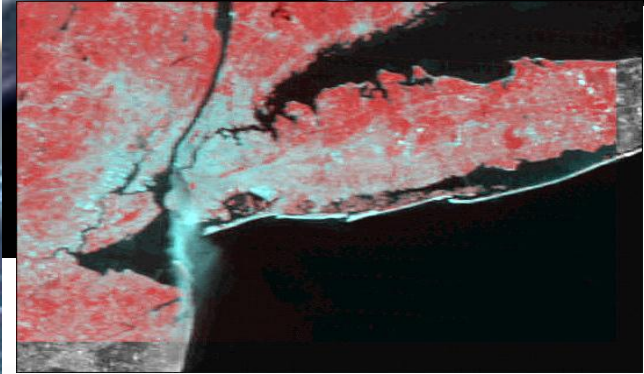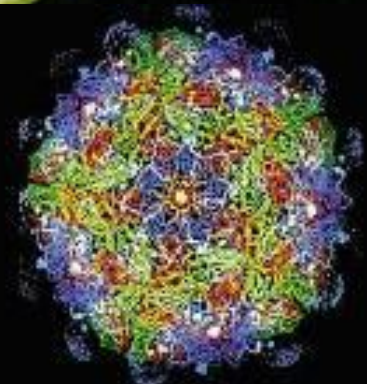
- Gilbert Brunet, Director Meteorological Research division
- André Méthot, Director National Prediction Development
- Richard Hogue, Director National Prediction Operations
- Bertrand Denis, on assignment NWP and HPC systems
- Jennifer Milton, Executive Director WEO
- John Parker, Manager Operations, Atlantic Region
- Dave Jackson, Director Canadian Ice Service
- And many others….

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A bit of context….

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NWP… more than
« *what's the weather going to be tomorrow?* »

Dealing with increasing vulnerabilities

The Future for the Meteorological Service of Canada

- Our Vision: Enable Canadians and policy-makers to take appropriate actions to enhance their benefits and reduce their risks to significant changes in weather, climate, water and air quality.

- Implement a strategic vision for our weather and environmental services that responds to emerging environmental, societal and political landscapes and realities by:

  - Strengthening our operational, predictive and alerting capacity;

  - Providing Canadians with end-to-end seamless weather and climate services at all time scales to support decision-making in adapting to variable weather and climate conditions;

  - Enhancing our services to meet the emerging demands for weather and environmental information in Canada's vast Northern Territory, in support of safety and security.
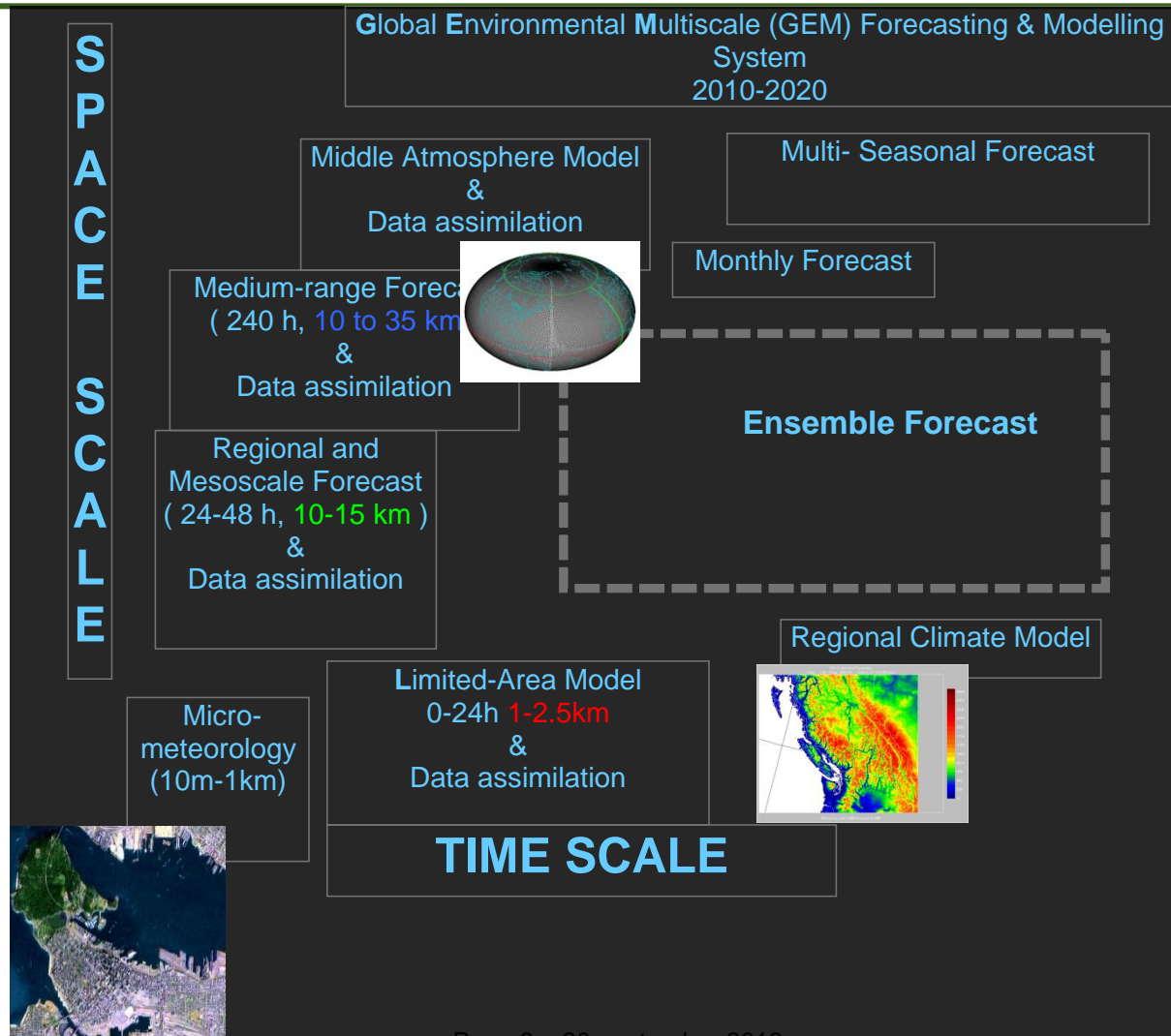
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How do we do reach that goal?

By enabling a multi-hazard multi-scale weather and environmental alerting platforms from nowcasting to climatological timescales that takes into consideration the complete cycle relating weather to impacts and the underlying infrastructures (social, physical and environmental)

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An unified numerical forecasting system for seamless (e.g. multi-scale and multi-disciplinary) applications

SPACE SCALE

Global Environmental Multiscale (GEM) Forecasting & Modelling System
2010-2020

Middle Atmosphere Model
&
Data assimilation

Multi- Seasonal Forecast

Monthly Forecast

Medium-range Forecast
(240 h, 10 to 35 km)
&
Data assimilation

Ensemble Forecast

Regional and Mesoscale Forecast
(24-48 h, 10-15 km)
&
Data assimilation

Regional Climate Model

Micro-meteorology
(10m-1km)

Limited-Area Model
0-24h 1-2.5km
&
Data assimilation

TIME SCALE

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Our Limitations

- However, countries are subject to fiscal constraints which pose a number of challenges, including the lack of funding to address core program integrity requirements in the near-term;

- This means that our collective way forward will need to be:
  - *Focussed* – by addressing priority infrastructure initiatives that are the most critical to the integrity of the weather, water and environmental enterprise;
  - *Innovative* – by rethinking the use of our current resources and how we share knowledge and capabilities;
  - *Strategic* **– by making choices with respect to when, where and with whom we engage**

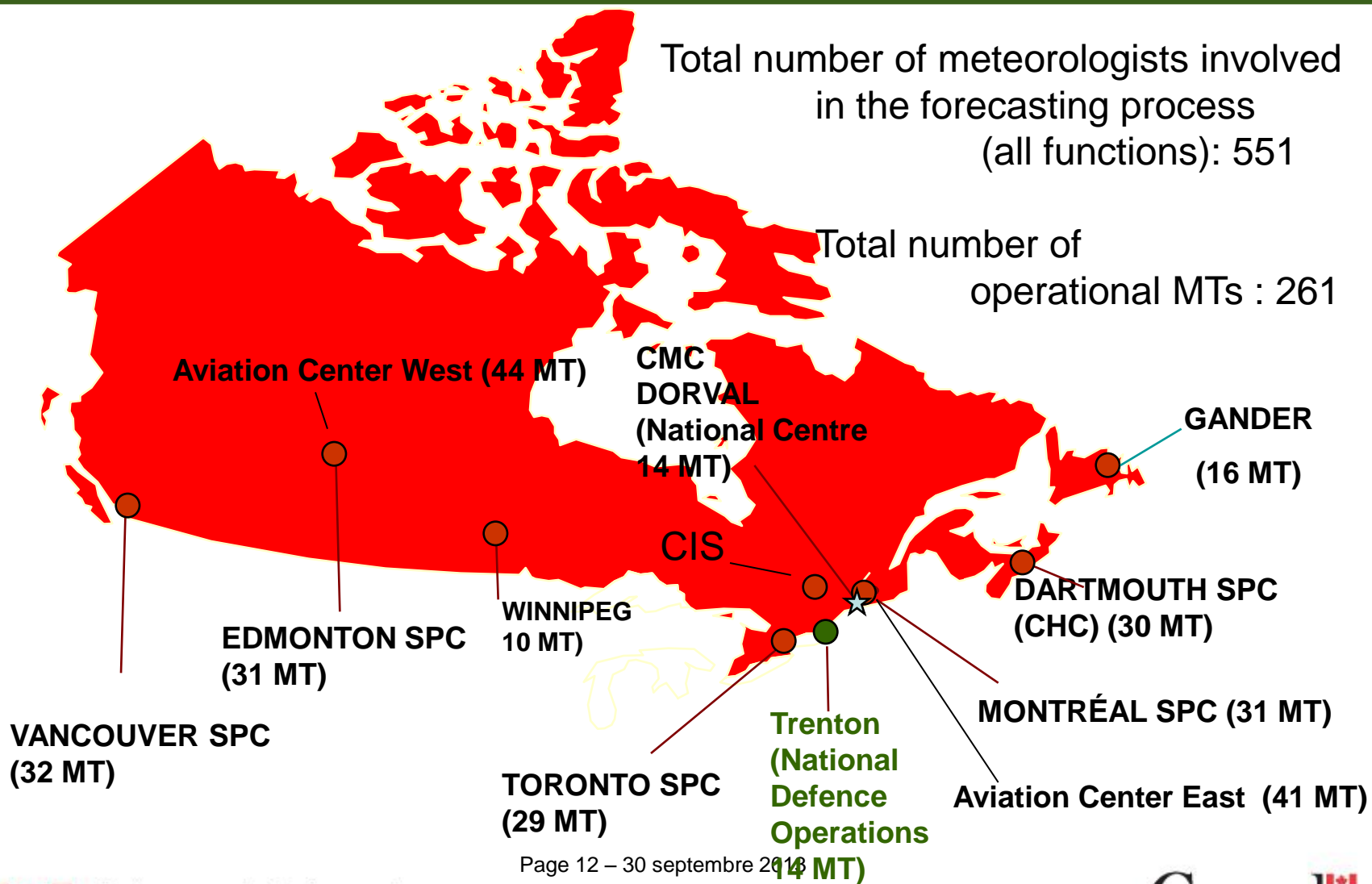Environnement Canada   Environment Canada

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Where we are…

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Main Centres of the Meteorological Service of Canada

Total number of meteorologists involved in the forecasting process (all functions): 551

Total number of operational MTs : 261

Aviation Center West (44 MT)

CMC DORVAL (National Centre 14 MT)

GANDER (16 MT)

CIS

DARTMOUTH SPC (CHC) (30 MT)

WINNIPEG 10 MT)

EDMONTON SPC (31 MT)

VANCOUVER SPC (32 MT)

MONTRÉAL SPC (31 MT)

Trenton (National Defence Operations 14 MT)

TORONTO SPC (29 MT)

Aviation Center East (41 MT)

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Canadian Meteorological Centre

Meteorological Research Division: Data Assimilation, Modeling, Cloud Physics

CMC Development Division: Data Assimilation, Numerical Weather Prediction, Weather Elements, Scientific Applications

IT Infrastructure (CIOB): Supercomputer, National Telecommunications, Network, User support

CMC Operations: Analysis &Prognosis, Env. Emergency Response, Air Quality, Implementation and Operational Services

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IBM p5 4224 PEs

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Canadian Meteorological Centre (CMC) : a critical centre of the MSC

- National Meteorological Center (24/7, year round)
  - Canadian equivalent to NCEP

- Emergency response capacity
  - Canadian equivalent to LLNL NARAC
  - WMO Regional Specialized Meteorological Centre for **nuclear emergency response**.
  - ICAO **Volcanic Ash Advisory**.

- **Critical component of the air navigation** system (NavCanada) are located at CMC (forecasts, observations, telecommunications) due to the informatics infrastructure and UPS

- Telecommunication network for Environment Canada (**GTS** hub)

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CMC-MRD unified multi-scale model : GEM

GEM= Global Environmental Model
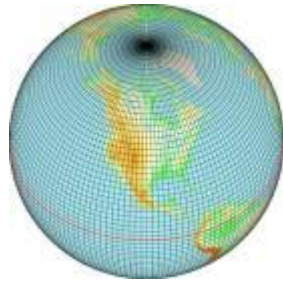
- Global constant resolution (regular lat-lon grid) (GEM-Global)

    –Medium-range deterministic forecasts (33 km)

    – Seasonal forecasts / Climate simulations (100 -200 km)

    –Medium-range EPS (100 km)
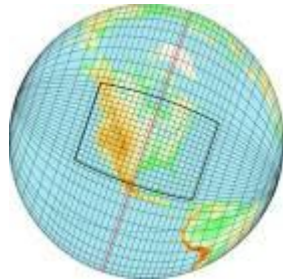
- Global variable resolution (stretched grid)

    – Short-range deterministic forecasts (GEM-Regional 15 km)

   – Regional climate simulations (55 km)
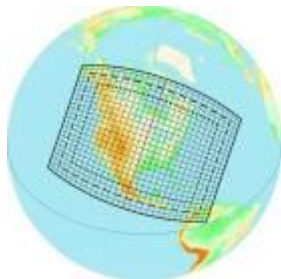
- Limited-area (LAM) constant resolution lat-lon grid

    –Short-range high-res. deterministic forecasts (GEM-LAM 2.5/1.0 km)

    – Urban emergency response (250 m)

    – Regional climate simulations (15-55 km)

    – Short-range EPS (33 km)

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RMS Errors for day 2 and day 5 forecasts of GEM (33km) over North America
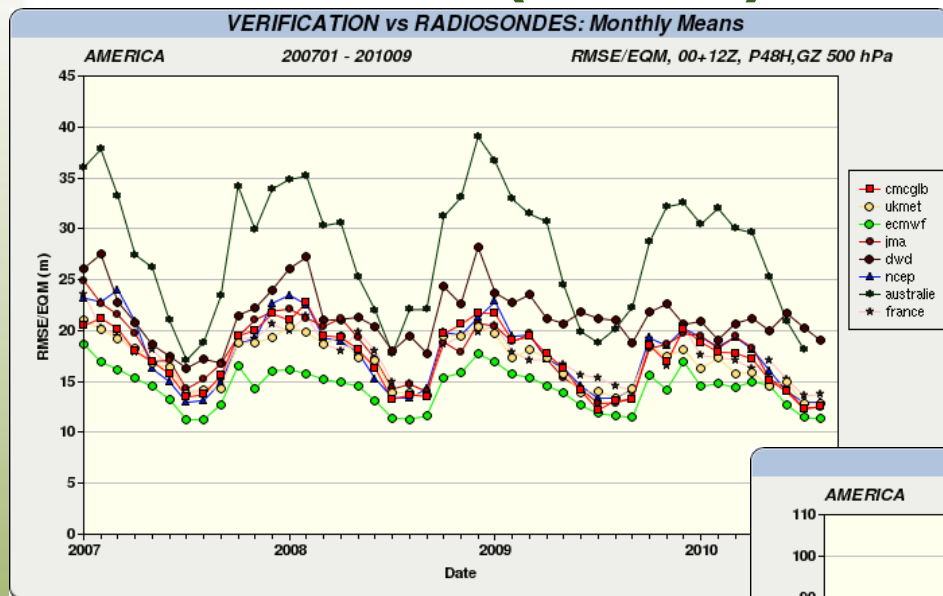
48h 500mb forecast

Verification period:
2007-2010
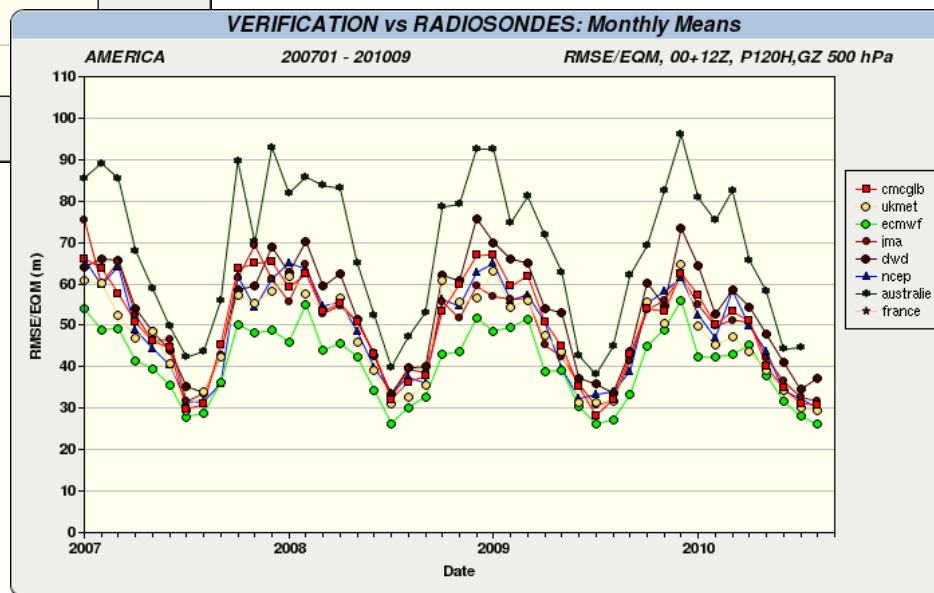
120h 500mb forecast
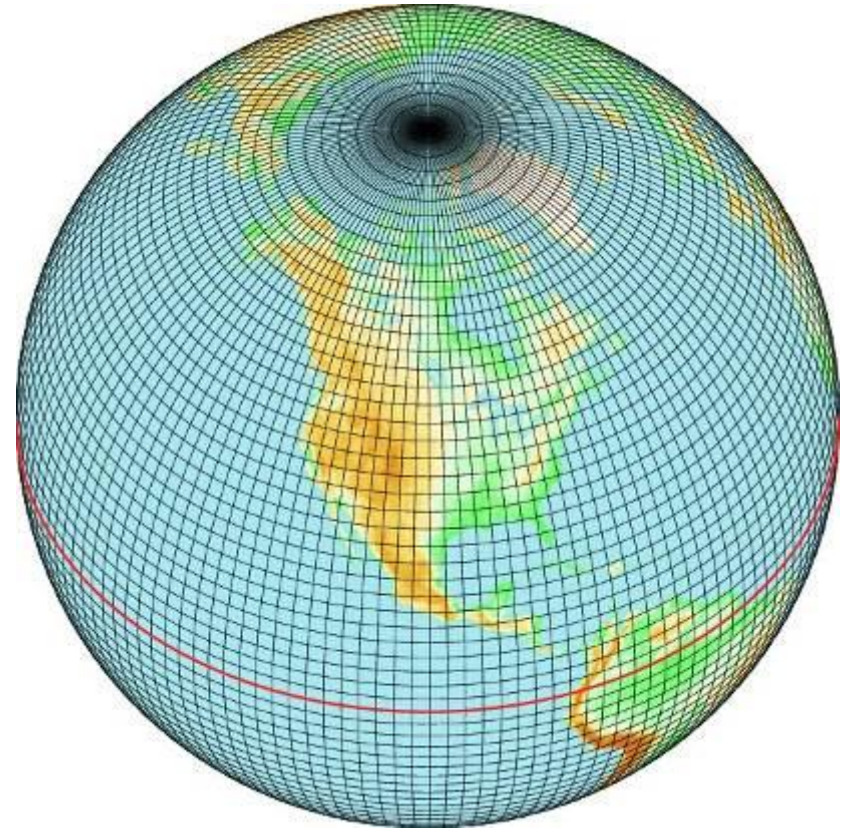
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Analysis & Prediction at CMC
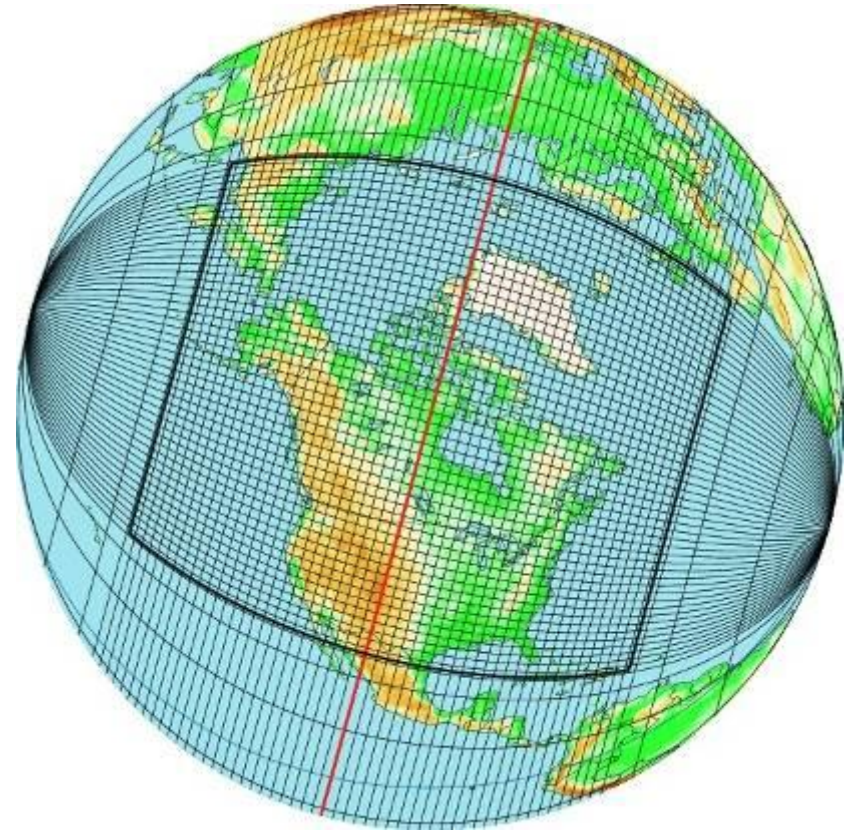
- Weather **Analysis**:

    - Global assimilation system
      4DVar;

      Four times daily;

      33 km resolution.

    - Regional assimilation system
      3DVar;

      Four times daily;

      15 km resolution

    - Ensemble assimilation system
      Ensemble Kalman Filter;

      96 analyses produced 4x daily;

      20 members in forecast mode (100 km resolution)

Global grid
(not all grid lines shown)

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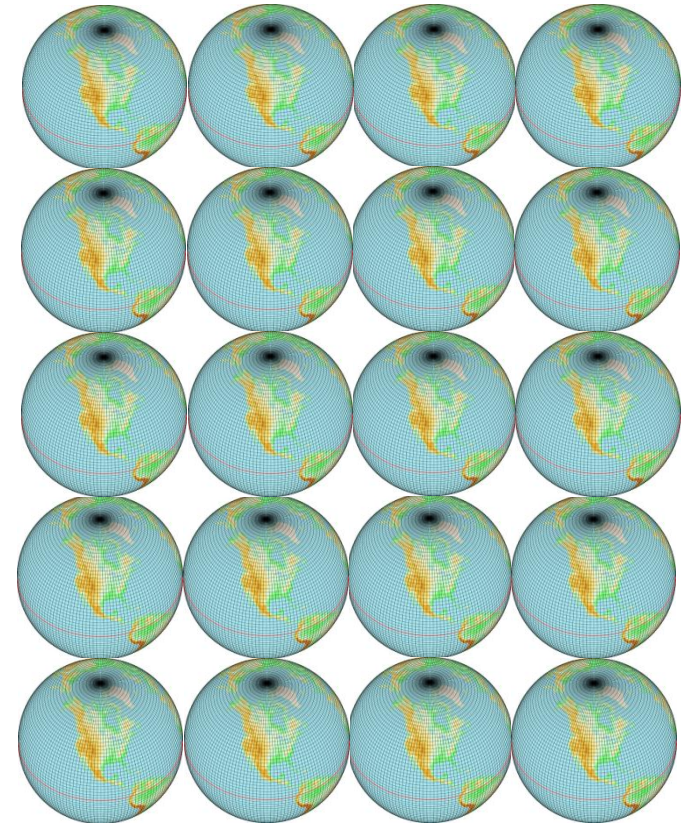# Analysis & Prediction at CMC

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Regional grid
(not all grid lines shown)

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Analysis & Prediction at CMC

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Ensemble system

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Analysis & Prediction at CMC

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  - Ensemble assimilation system
    Ensemble Kalman Filter;

    Once daily;

    20 members, 100 km resolution
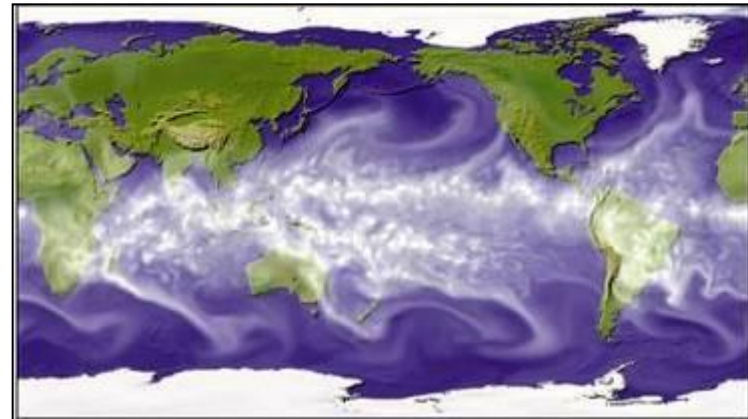
Set of surface analysis produced daily:

Snow, Ice, SST, Surface temperature,
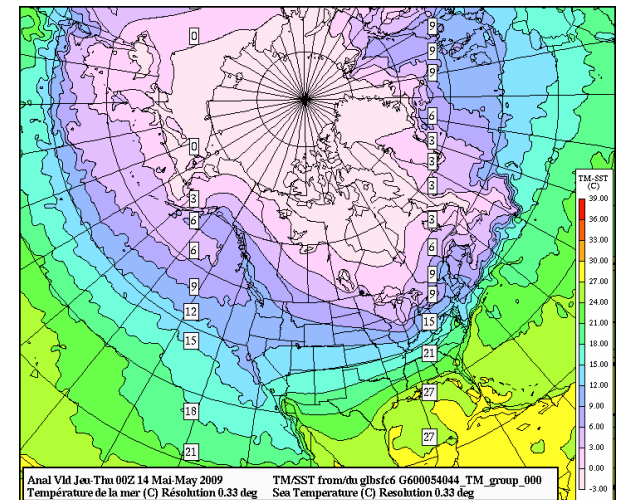
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Analysis & Prediction at CMC

- Weather & Seasonal **Forecasting**:

  - Medium range (7-day*)* forecast
    Global 33 km resolution grid

  - 48/54-hour forecast
    Regional 15 km resolution grid

  - 24-hour forecast
    4 Limited-Area 2.5 km resolution grids

    + 1 km resolution grid over the 2010 winter Olympics

  - Extended-range (16-day) ensemble forecast
    20 members 100 km resolution

  - Seasonal (4-month) ensemble forecast
    40 members 200-500 km resolution

Global forecast

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Analysis & Prediction at CMC

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15 km resolution forecast of cloud fraction

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Analysis & Prediction at CMC

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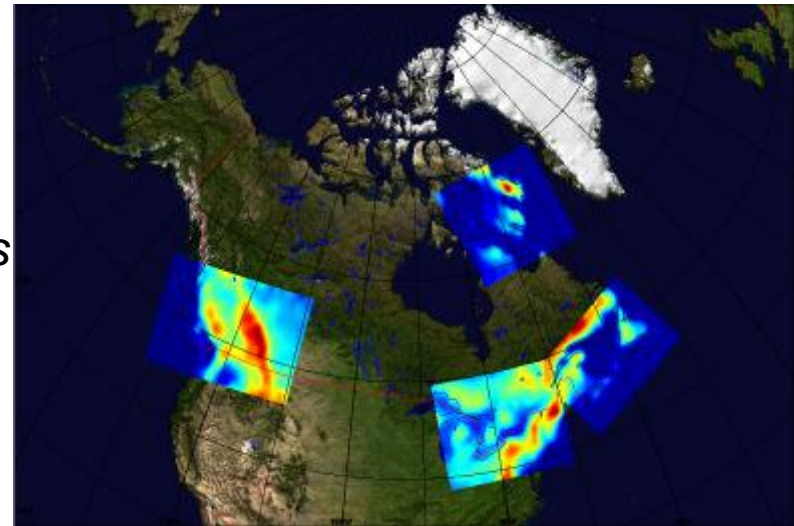   *4 Limited-Area 2.5 km resolution grids*

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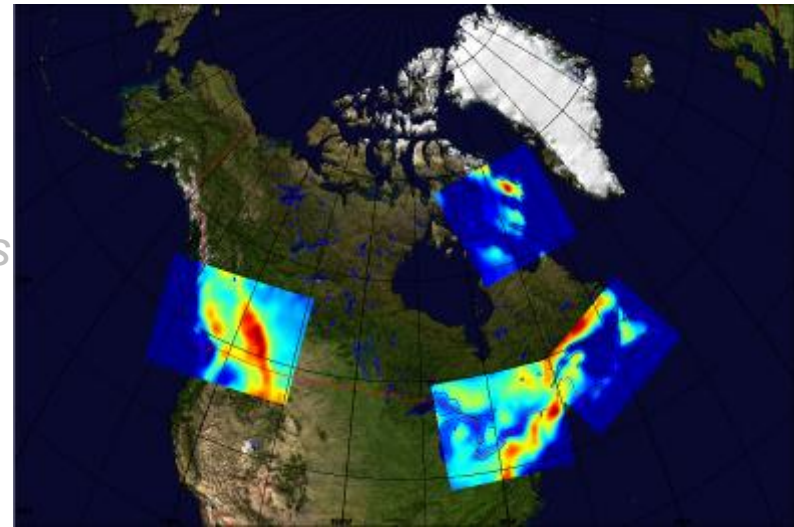   *40 members 200-500 km resolution*

Four grids with 2.5 km resolution

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Analysis & Prediction at CMC

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Analysis & Prediction at CMC

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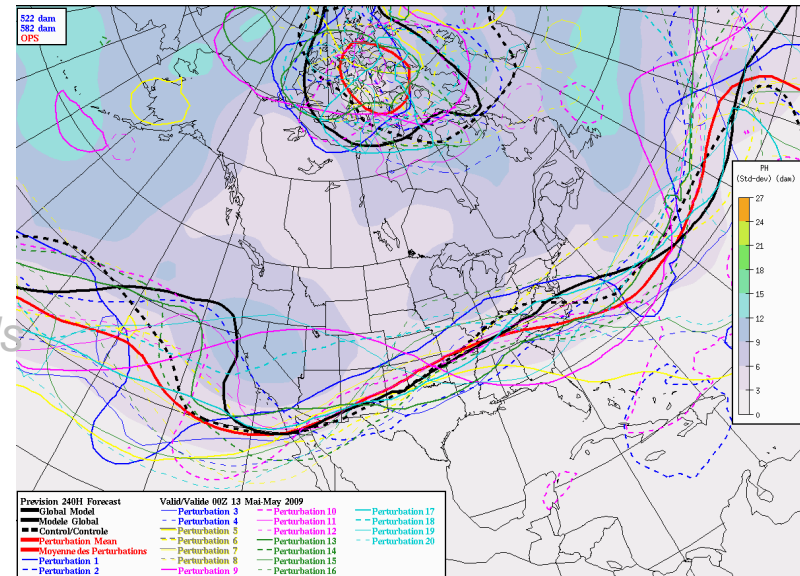   *4 Limited-Area 2.5 km resolution grids*

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Ensemble forecast

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North American Ensemble Forecast System (NAEFS):
Joint project involving MSC, NWS and the NMSM

Analysis & Prediction at CMC

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Seasonal Forecast
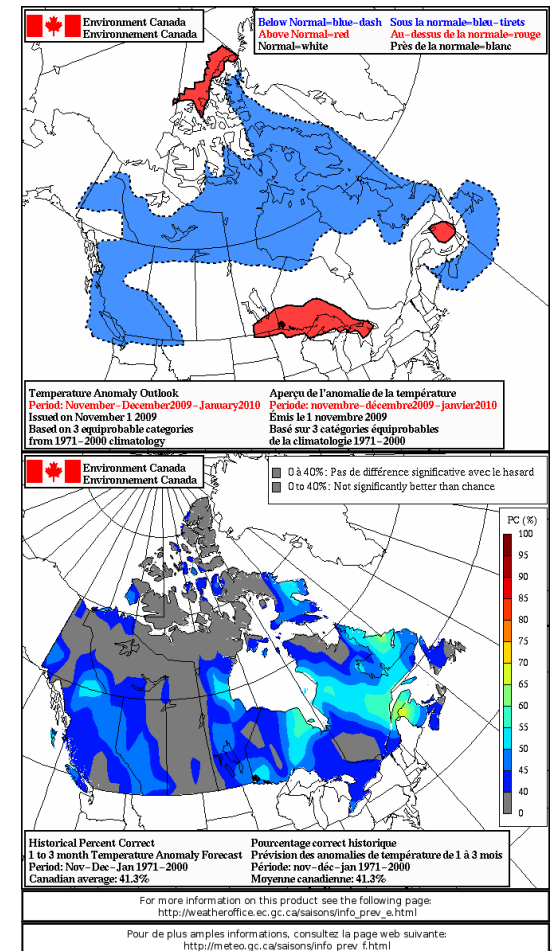
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- ## Wave Forecasting:

  – Spectral Wave Model (WAM)

    48-h regional / 120-global forecasts of wave height and period, swell height and period, and wave and swell directions;

    *Regions: Pacific, Atlantic and Canadian Great Lakes (**and Arctic for DND**)*

- ## Air Quality Forecasting

  – GEM-MACH : in-line chemical and weather model recently implemented (No 2009)

  48-hour forecasts of tropospheric ozone, NO$_2$, PM2.5 and PM10 for North America

Global WAM – Atlantic domain

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Analysis & Prediction at CMC

- Wave Forecasting:
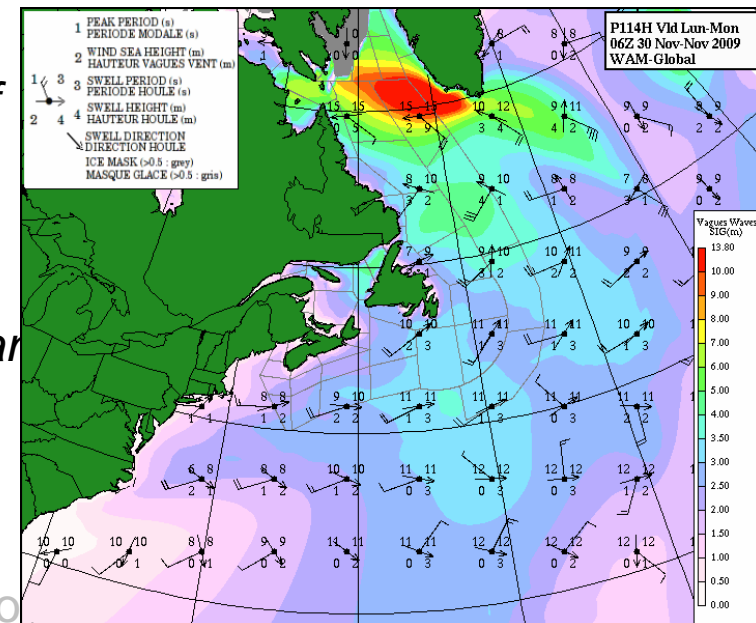
  – Spectral Wave Model (WAM)

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    48-hour forecasts of tropospheric ozone, NO_2, PM2.5 and PM10 for North America

GEM-MACH

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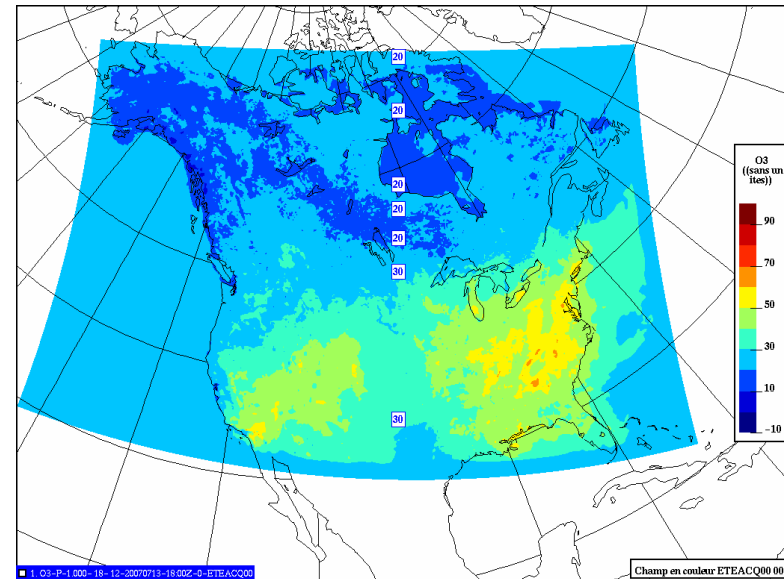
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- Environmental Emergency applications – dispersion modeling
  - Nuclear and volcanic ash
  - Release of hazardous chemicals
  - National security issues

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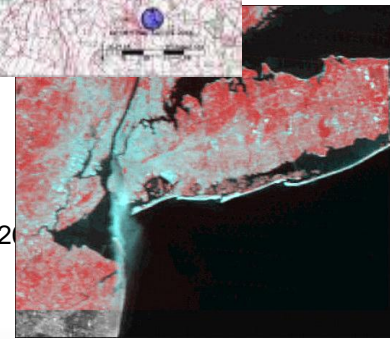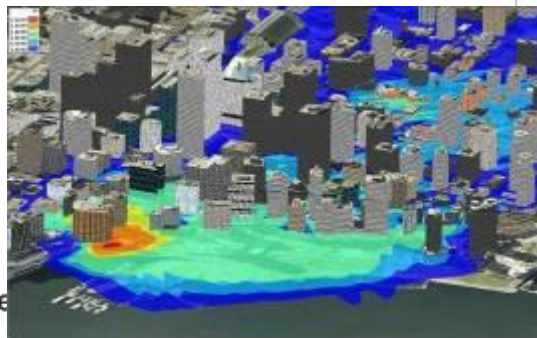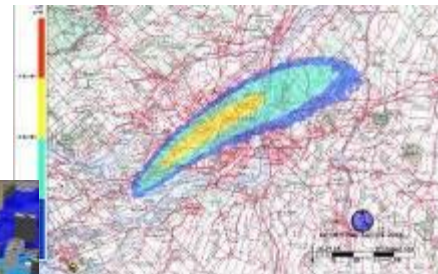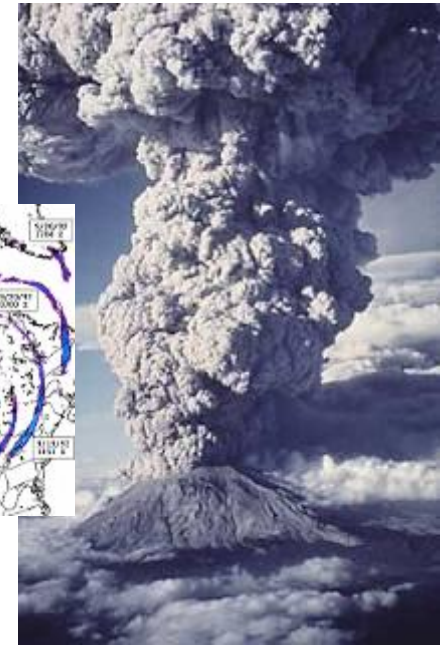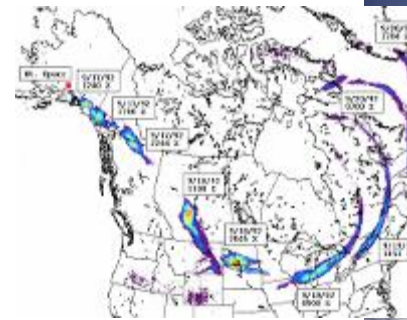
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Aviation weather in Canada:
A unique situation

- a private, not-for-profit company (NAV CANADA) contracts with the MSC for aviation forecast services
- Over the past 15 years, many changes to focus on aviation
  - Consolidated all aviation forecasting into 2 locations (Montréal and Edmonton… roughly 90 forecasters in total)
  - Dedicated aviation forecasters and training
  - Specialized software to assist with workload management, monitoring and alerting, forecast generation
  - Reaching out to end users, getting to know their operations
  - Experimenting with new products
- Synergies with the MSC's public weather program
- The end result is a system that's efficient, much more responsive to aviation needs
- It's well set-up to handle today's needs, but we need to make more changes to handle tomorrow's needs

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Where we are heading

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Main recent improvements completed or nearing completion

- 200% increase in the data volume assimilated in the deterministic systems (Global & Regional): more IASI, AIRS and SSMIS channels, reduced horizontal thinning for satellite radiances, humidity from aircraft, etc.

- New Global Sea surface temperature analysis

- Global EPS: lid to be raised from 10 to 2 hPa, number of levels from 28 to 40, horizontal resolution from 100km to 66km

- Experimental Regional EPS (North America coverage)

- Coupled atmos-ocean-ice modeling system in the Gulf of St-Lawrence

- Regional LAM continental: resolution to be upgraded from 15km to 10km

- A new one-tier (fully coupled) multi-seasonal forecast system (up to 12 months). It will replace the current two-tier (uncoupled) seasonal forecast system as well as the statistical (CCA) multi-seasonal forecast system.

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Aviation weather in Canada:
Where we are heading

- The desire to have weather factored more into users' decision-making systems

- Need to replace our ageing software… will be using our new forecaster workstation ("NinJo") but it needs to be supplemented by other programs to create and deliver aviation-specific services

- The future portends the use of first-guess fields and forecasts, forecast data in digital form

- Believe in targeted forecaster intervention… still a need for the human in the loop… a pilot in the seat…

- As aviation is international in scope, the need to collaborate and exchange data with others, especially the USA (re NextGen Wx)

- We are developing a comprehensive plan… we are open to ideas

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Longer term …..

- Data assimilation…. 4-D Var, KF or Hybrid ?

- Broadening of applications (agriculture, forestry, health, energy, ecosystem, emergency response)

- Further significant increases of satellite data;

- Further increase in main model resolutions with emphasis in ensemble forecasting approaches (probabilistic forecasts)

- Urban meteorology… towards capabilities to provide guidance at the urban scale (air quality applications, release of hazardous material, etc.)

- Integrated multidisciplinary approach to environmental prediction (coupled atmosphere-ocean-ecosystem, air quality (chemistry);

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Evolution of core systems

	2011	**2015**	**2020**

Global

	2011	2015	2020
Global	Det. 33 km EPS *66* km	Det. 20 km EPS 35 km	Det. 10 km EPS 20 km
Regional	Det. *10* km EPS *33* km	Det. 10 km EPS 15 km	Det. 2.5 km EPS 10 km
Local	Det. *2.5 km* EPS *2.5 - 4 km*	Det. *1.5 km* EPS 2.5 km	Det. *500 m* EPS 1.5 km
Urban	*Det. 250-> 5m*	Det. 3m EPS 5m	Det. 1m EPS 5m

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Will be operational this year   **Experimental**

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Emerging Integrated Environmental prediction system

Air quality and chemical weather

- Multi-scale approach: global down to human scale
  - Interfacing with effects models for human and ecosystem health
- Refinement of chemical processes to link with health triggers
- Full use of satellite, remote sensing and surface observations to inform integrated modelling system from emission to transport to effect

Feb 3rd, 2006 in Montreal

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Emerging Integrated Environmental prediction system

Applications

Forecasting Systems

Initial Conditions

SAM 2.0 (Ocean)

3D var Ice (Sea + lakes)

Caldas (Land + Snow)

Capa (Precipitation)

DND Operations

Transportation

Search & Rescue

Energy

Water Resource Planning

Ecosystem

Agriculture + Fire

Recreation

Global Ocean - Ice (Fully Coupled)

Regional Ocean+GL-Ice (Fully Coupled)

Ocean-Ice-Waves (Forced)

Wind Energy

Hydrological + Hydrodynamic (Forced)

Land + Snow (Fully Coupled)

High-Res Land Surface-Urban ((Forced)

Nowcasting

Deterministic (1-2 days)

Probalistic (1-3 days)

Deterministic (2-10 days)

Probalistic (3-16 days)

Monthly + Seasonal

Forecast Lead Times

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Environmental Prediction System for the Great Lakes – St. Lawrence basin:

Towards an integrated Earth Science System for the Basin

• Operational system which predicts physical parameters of the earth system and ecosystem state variables
  – Nowcast and hindcast mode: interpolation of observations in space
  – Forecast mode: extrapolation in time

• Numerical models which deal with the dynamics and thermodynamics of the system
  - mass, energy and momentum balance

• System designed for decision making purposes
  – Improved weather forecasts
  – Management of international waters and ecosystem protection
  – Water quantity and water quality prediction
  – Currents, Water Temperature, Ice prediction
  – Emergency response
  - Adaptations and Studies
  - atmosphere, land-surface, hydrology, lakes, rivers, ice, waves, habitat

• A Collaborative Project:
  - EC (ASTD, NWRI, MSC), DFO, IJC, Universities

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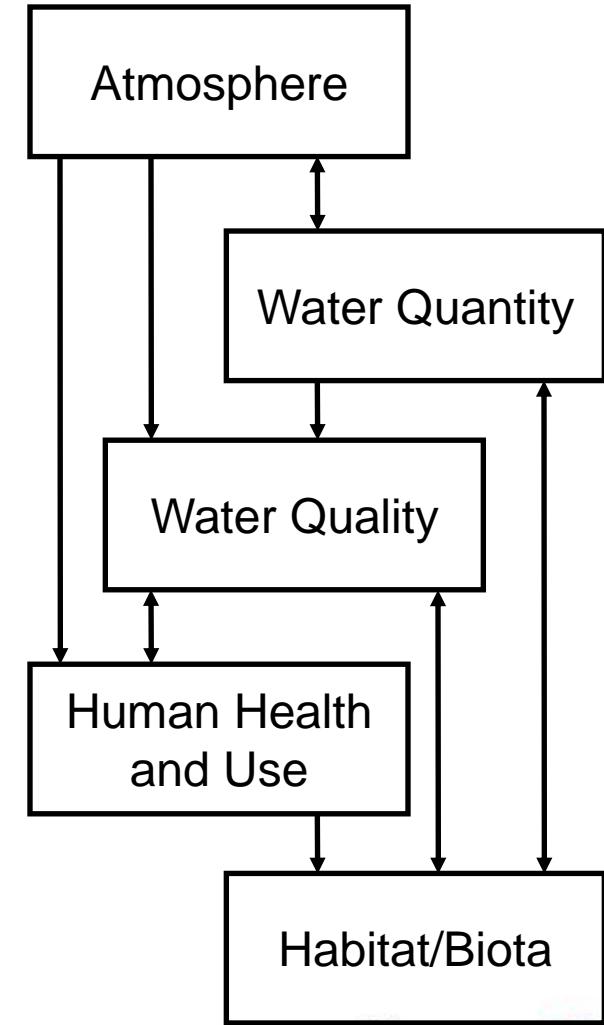
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Canadian Coupled Atmosphere- Ice Ocean Forecast System

Canada requires ocean forecasts and information services for:

- Weather prediction
- Sea ice prediction (e.g. CCG: seal hunt, navigation)
- Fisheries and aquaculture management
- Increased understanding of biological field observations
- Attribution and mitigation of regional climate change impacts
- Risk assessment for extreme events (sea level, waves, currents)
- Search and Rescue, dispersion of pollutants

Fisheries and Oceans Canada   Pêches et Océans Canada   Environment Canada   Environnement Canada   National Defence   Défense nationale   Canada

The Gulf of St. Lawrence forecast system:

- Initiated 13 years ago by the Maurice Lamontagne Institute (DFO) and Recherche en Prévision Numérique (EC)
- Between January and March is nearly entirely cover of Ice
- Ice conditions can change very rapidly
- Coastal weather forecasts are very affected by the ocean conditions.
- During the ice period, both systems are particularly interdependent.
- To improve the atmospheric forecasts (icing, clouds, fog,…)
- To improve the ocean-ice forecasts (ice, currents, temperature, waves…)
- To improve the services: Major Seaway
- Users: EC, coast-guard, DFO, maritime transportation, DND
- Very interesting laboratory: Semi-enclosed Sea

Gulf of St. Lawrence

N. Atlantic
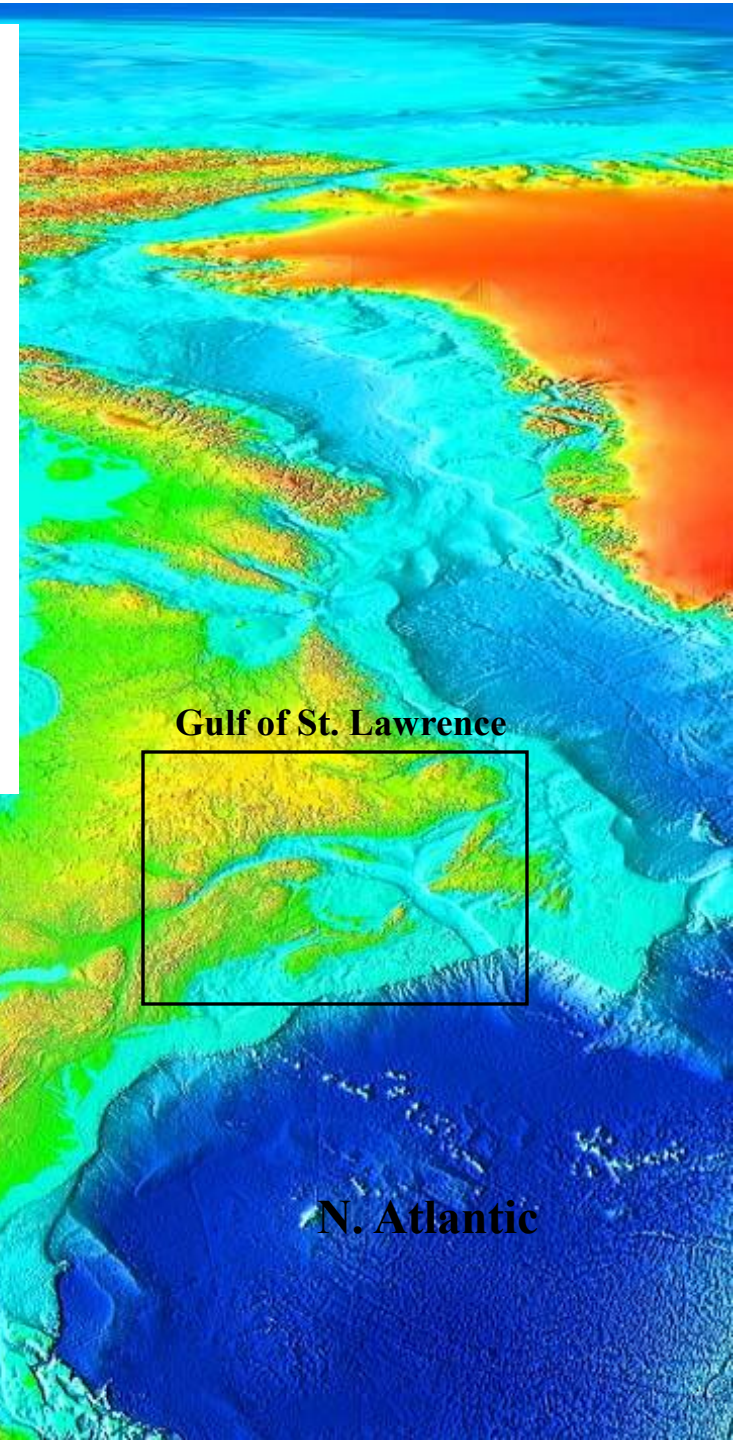
Fully Coupled system VS Operational GEM
(48 hours forecast)

Mont-Joli, 06 Feb. 2008

GEM Coupled

Observations

GEM Operational (Uncoupled)

~ 24 hours
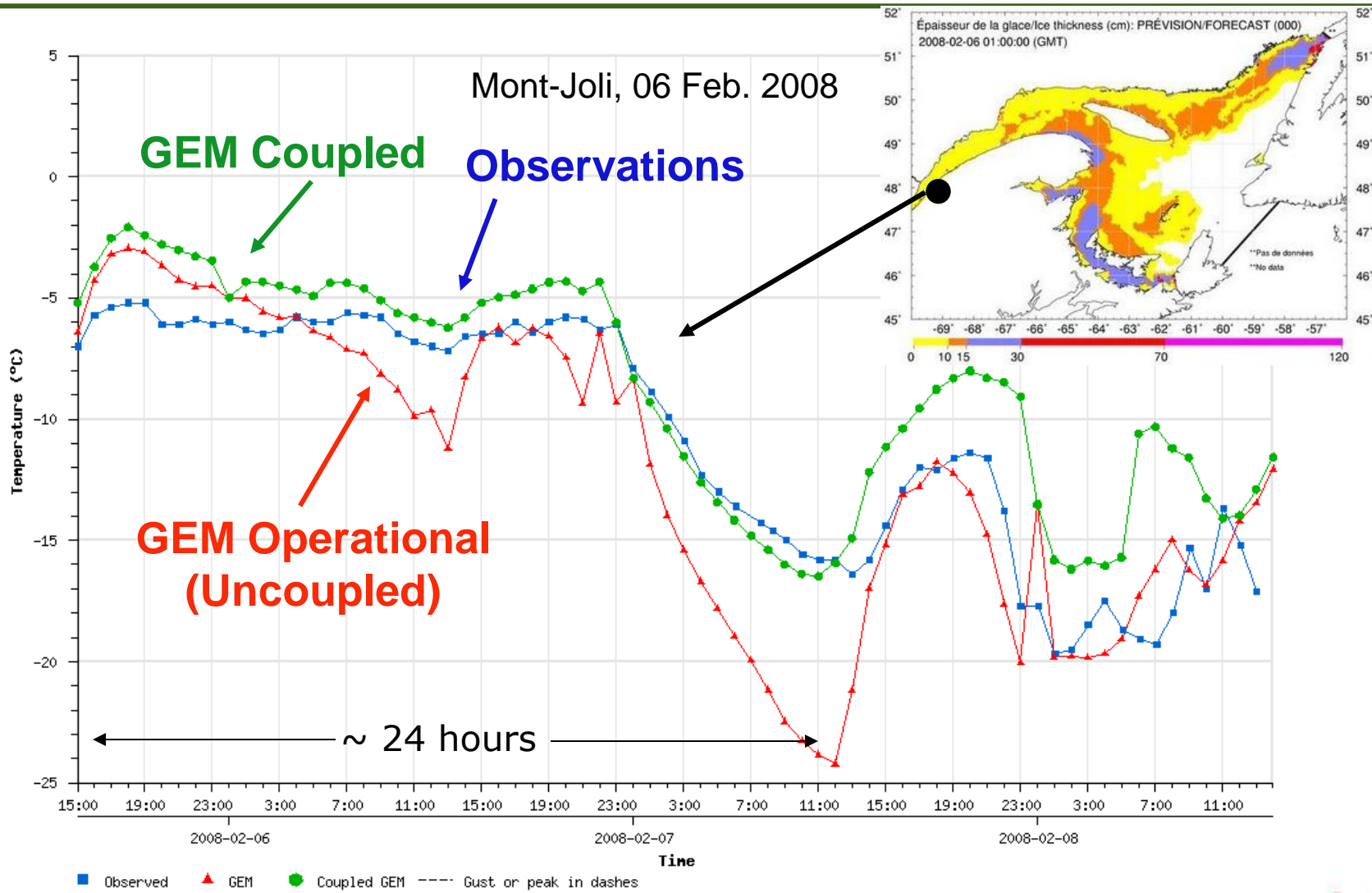
9/30/2013

PROPOSED METEOROLOGICAL MONITORING INFRASTRUCTURE (MET/NAV AREAS)
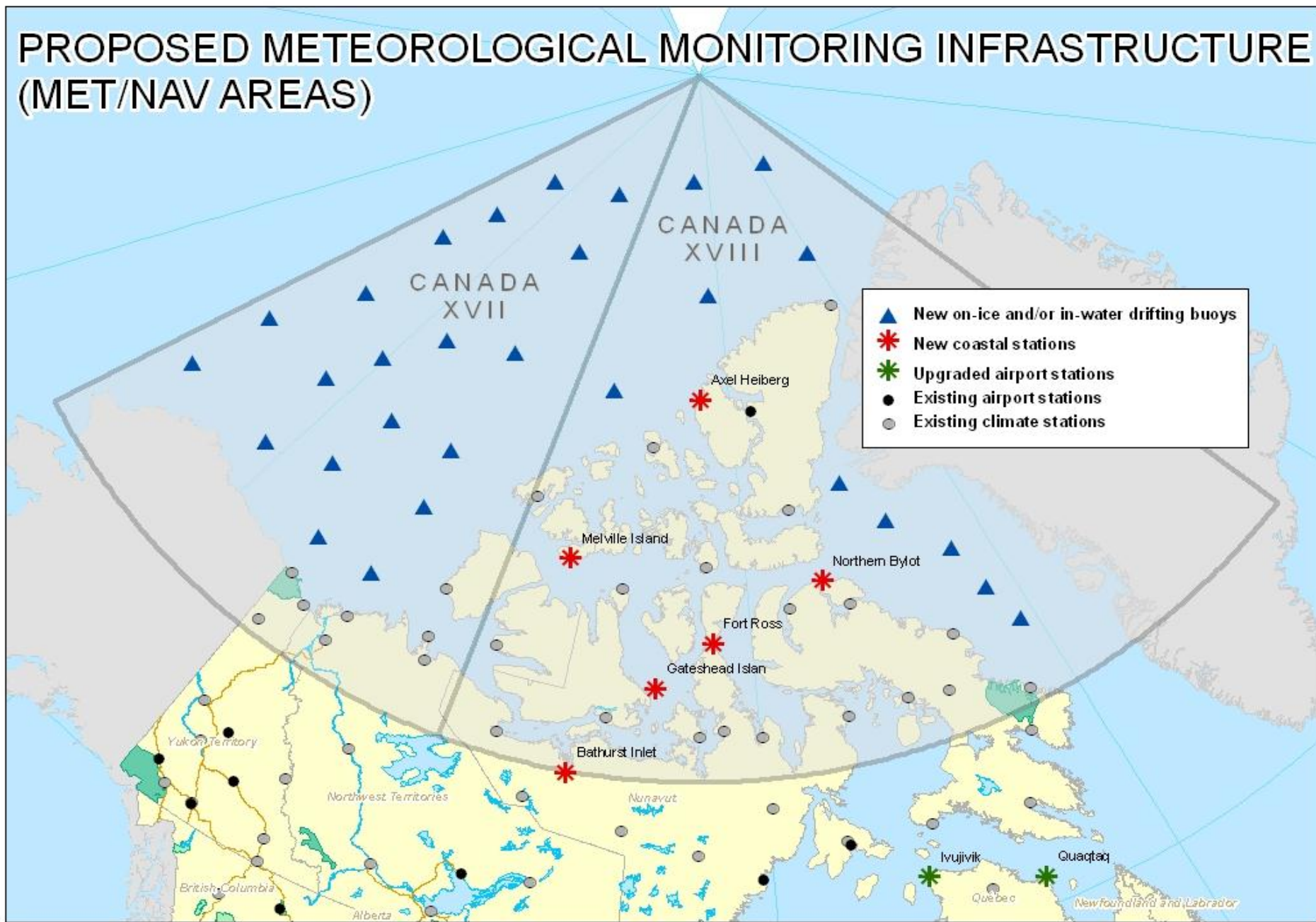
The Canadian Land Data Assimilation System (CaLDAS)

ATMOSPHERIC FORCING
- Met analyses and forecasts
- Precip analyses
- Adaptation (downscaling)

T, hu, winds
Precipitation
Radiation

ANCILLARY DATA

(databases for soil texture, vegetation, water/land mask, orography, cities)

EXTERNAL LAND SURFACE MODEL

OBS or ANCILLARY DATA ?

- *Albedo*
- *Emissivity*
- *Vegetation (fraction,*
- *height, LAI,*
- *root depth, …)*

OBS

- *Soil moisture* (screen-level, L-band – SMOS+SMAP)
- *Snow coverage fraction* (surface, MODIS, IMS)
- *Snow depth* (surface, AMSR-E)
- *Surface temperature* (screen-level, IR)

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Chemical, Biological, Radiological-Nuclear, and Explosives Research and Technology Initiative (CRTI) effort

Dispersion – urbanLS : concentration of hazardous material near the surface
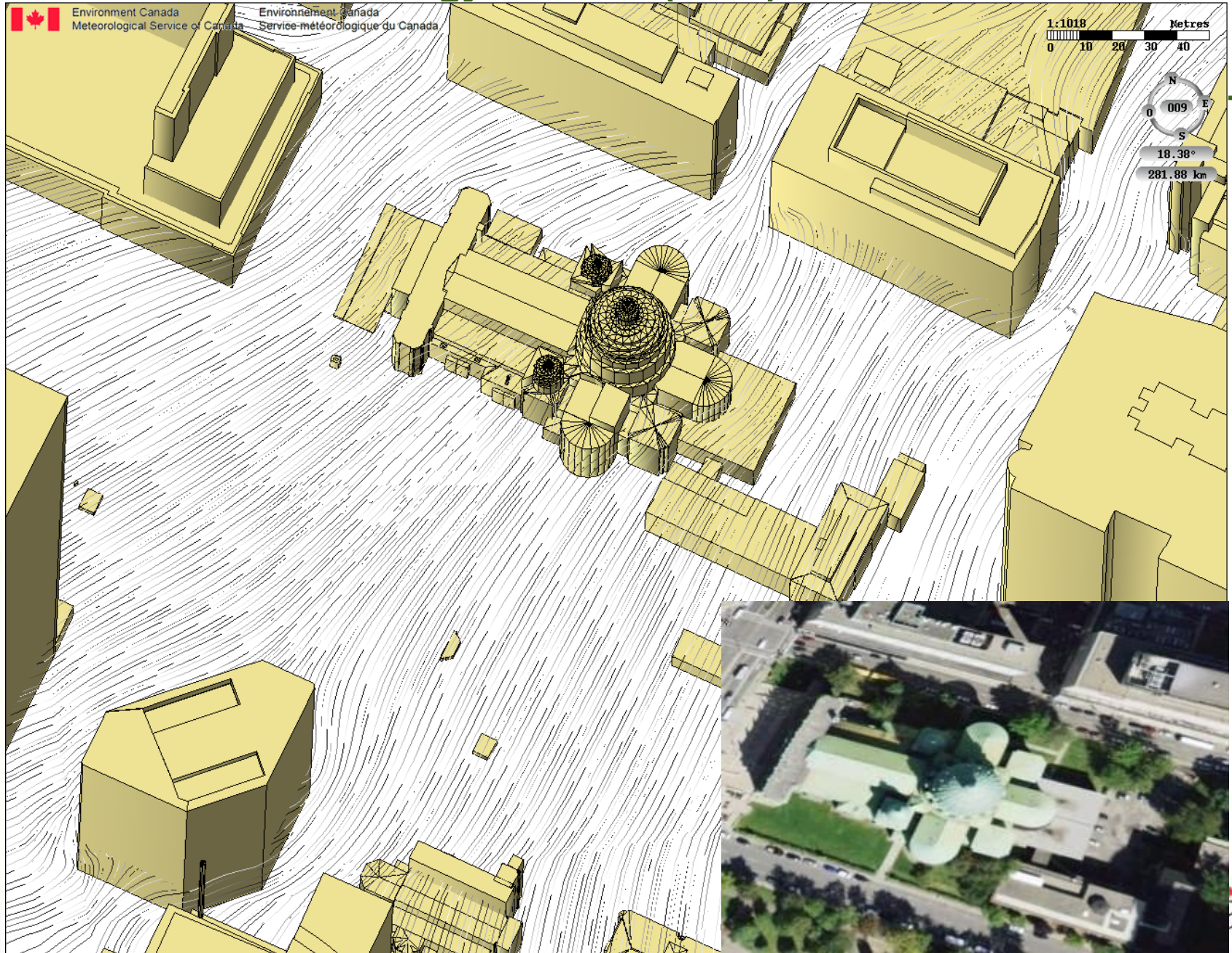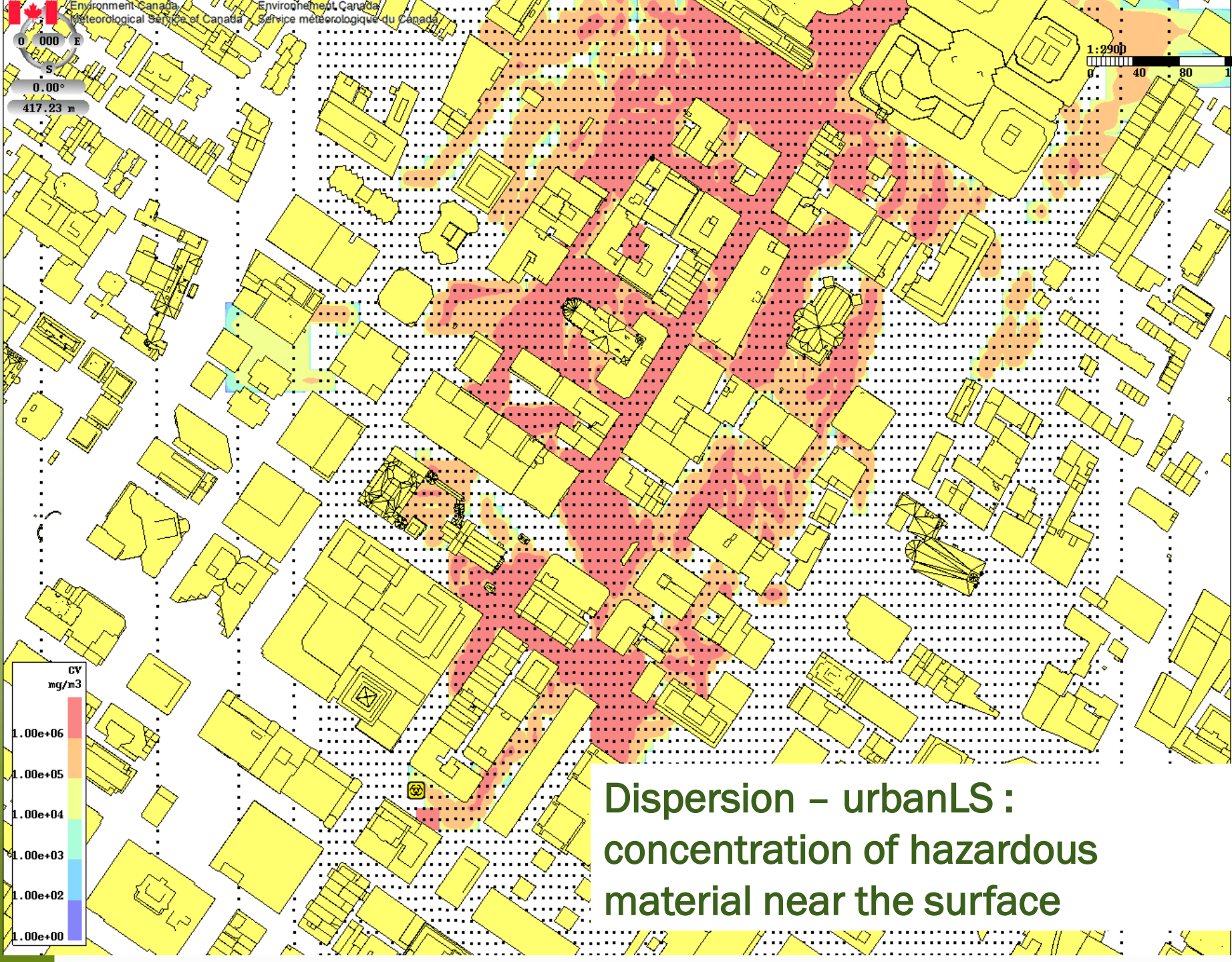
Key elements for the future roadmap…

Efficient Technology Transfer process :

Optimizing Research to Operations…

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The Innovation Chain:
a Technology/Service driven process

Stakeholders, clients and partners

OPERATION

SERVICES

Monitoring,
High-performance
Computing and Cyber
Infrastructures

DEVELOPMENT

RESEARCH

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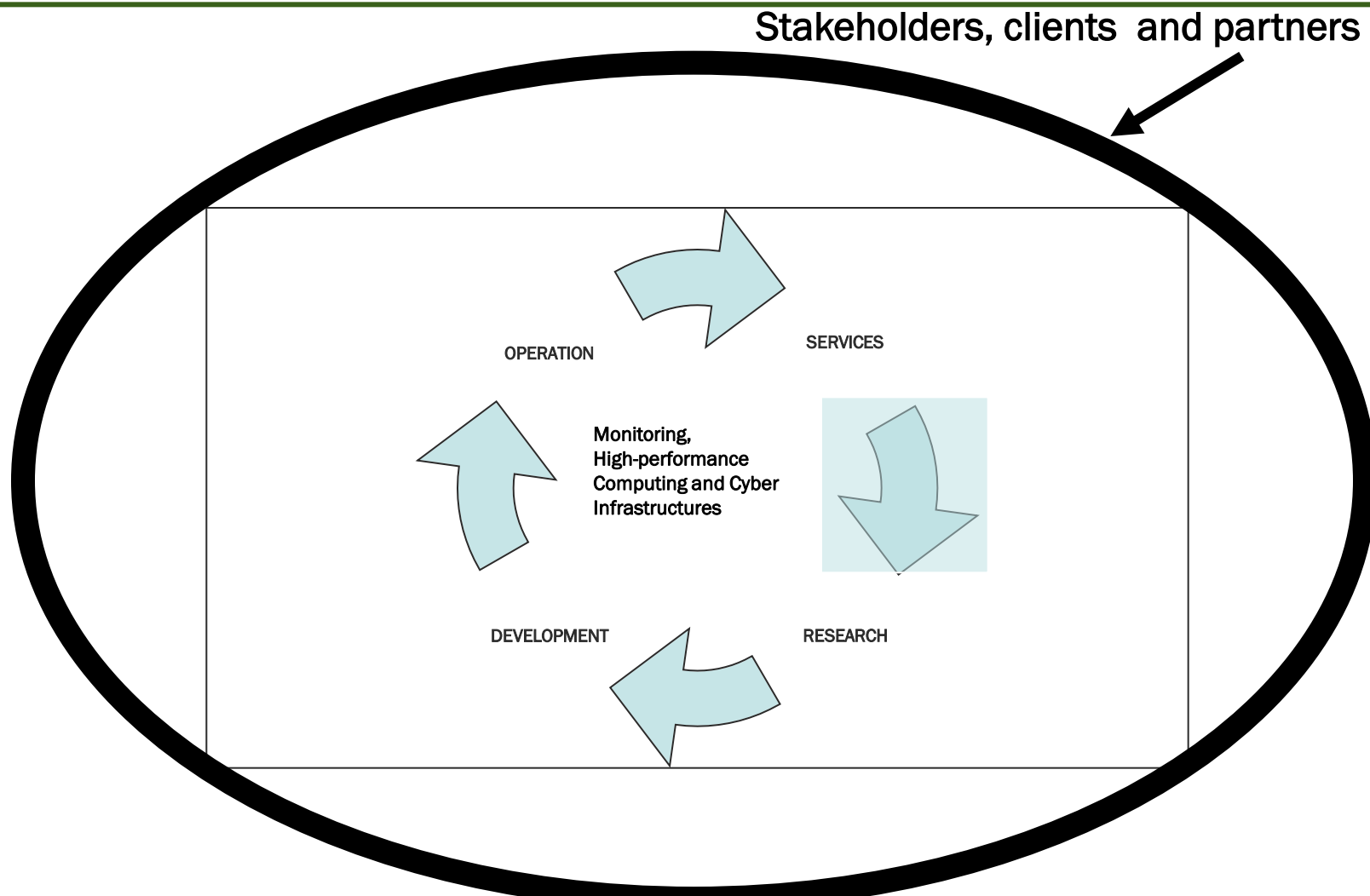
Numerical Prediction Innovation Committee Chair: DG Meteorology, Co-chair: DG S&T

- Members are all DGs and directors (including Services) responsible for the chain of innovation
- R&D section chiefs are invited to present their activities on a continuous basis
- ToR:
  – Implementation management of R&D innovations
  – Long term planning of future implementations, including resources allocations and re-allocations
  – Dissemination of short and long term plans

Implementing the NWP innovations into the operational context:

Comité des Passes Opérationnelles et Parallèles (CPOP)
(Operational and Parallel runs Comittee)

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Key elements for the future roadmap…

Implementing key

« Signature projects »

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Charting a course for the future of weather forecasting within the MSC

Identifying Key strategies that integrates the vision and mandate of MSC (signature projects):

- Monitoring Strategy – implementing network of networks approach
- High Performance Computing Strategy
- Enabling Environment Canada's science plan (integrated monitoring and prediction)
- Next Generation Weather Forecasting System
- Water and water cycle prediction system
- Modernized Weather Warning and Service Delivery System
- Climate Services Strategy
- Air Quality and health
- METAREAS

Integrating specific programs and tools dealing with the detection, evaluation and information of weather related risks and impacts

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National Lab Research Themes/Roles

- **Atlantic Lab for Marine and Coastal Meteorology**
  - Role: Improved scientific understanding and prediction of high-impact meteorology in marine and coastal environments.
- **Québec Lab for Severe Weather Meteorology**
  - Role: Improved prediction of severe weather processes with numerical weather prediction models.
- **Ontario Lab for Nowcasting and Remote Sensing Meteorology**
  - Role: Improve detection and prediction of severe weather processes in all seasons at time scales from 0 to approximately 12 hours.
- **Prairie and Northern Lab for Hydrometeorology and Arctic Meteorology**
  - Role 1: Improved detection and prediction of Arctic high-impact meteorology.
  - Role 2: Improved prediction of hydrometeorological processes.
- **Pacific and Yukon Lab for Coastal and Mountain Meteorology**
  - Role: Improved detection and prediction of high-impact meteorology in complex terrain and urban environments.
- **National Lab for Aviation Meteorology (Virtual laboratory)**
  - Role. To undertake R&D in aviation meteorology with the goal of providing more accurate, more relevant and timelier forecasts in order increase the safety and efficiency of aviation operations.

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HIGH PERFORMANCE COMPUTING STRATEGY

Monitoring Strategy
(Network of networks)

Water Cycle Prediction Services

Integrated Environmental Prediction Strategy
(EC's Science Plan)

MetNav

Next Generation Weather Forecasting System

Climate services

Modernized Weather Warning and Service Delivery System

WES for Canadians in respect to EC mandate and mission

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Key elements for the future roadmap…

Role of the

operational forecaster

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Vision to Role of the forecaster…

- Forecast system needs to change to achieve the Vision:
  - Monitoring
  - Prediction
  - Science
  - Services
- Defining, refining and realizing the forecasters role in the system is essential to achieve the Vision. The role must:
  - Facilitate the best application of human's skills;
  - Make the best use of technological progress;
  - Enable adaptability and responsiveness to client requirements;
  - Support effective decision making by enabling the forecast of impacts.

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Thrusts for the Role of the Forecaster

- Forecast production
  - moving to oversight and intervention in a decision making system.
- Client oriented
  - moving to the seamless integration of client relationships within the full forecast system.
- Science and Development
  - moving to the seamless application of science results to meet client requirements…
    - But science should not be subdued by the Service functions
- Learning
  - moving to forecasters with appropriate skills in a system of continuous skill renewal
- Organization
  - moving to an adaptively managed system to minimize societal risks to high impact weather.

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Charting a course toward the future

- An efficient technology transfer process

- Implementing key « signature » projects

- A vision for the role of the forecaster in this road towards the future

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Summary… a Canadian perspective

- Canadians demanding more and better integrated environmental information to support decision-making:
  - Mitigate increasing vulnerability of society, economy and infrastructure in face of increasing severity & occurrence of high impact events such as severe weather and pollution episodes
  - Know the risks and adapt to a changing climate (extreme weather, development of the North, etc…)
  - Maximize efficiency of economy and operations
  - Reduce emissions and avoid health risks of pollution exposure
  - Support sustainable use and development of natural resource
- Integrated multidisciplinary approach to environmental prediction
  - coupled atmosphere-ocean-ecosystem (whole-earth simulation), air quality (chemistry)
- Broadening of applications
  - emergency response, ecosystem, agriculture, forestry, health, energy

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Summary… supporting a broad and global perspective

- Global community of NMHS hold a key role in providing the vision, expertise, products and services related to multi-hazards environmental alerting platforms

- The international framework must include key partnerships and provide a reliable and sustainable infrastructure on which the vision of disaster risk reduction activities will ensure that its purpose is met.

- Improvements in understanding weather, water and environmental processes, such as in the oceans and polar areas will improve global environmental modeling

- Development and sharing of expertise, knowledge and practices will enable scientific and technical education and training, provide a sound basis for current and future generations in dealing with environemental hazards.

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Vision to Role

- Forecast system needs to change to achieve the Vision:
  - Monitoring
  - Prediction
  - Science
  - Services
- Defining, refining and realizing the forecasters role in the system is essential to achieve the Vision. The role must:
  - Facilitate the best application of human's skills;
  - Make the best use of technological progress;
  - Enable adaptability and responsiveness to client requirements;
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Thank you !